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EDITOR, C. A. CHANT ASSISTANT EDITOR, F. S. HOGG

David Dunlap Observatory
Richmond Hill P.O., Ont.

ASSOCIATE EDITORS

R. MELDRUM STEWART
Dominion Astronomer
Ottawa

J. A. PEARCE
Head Astronomer
Dominion Astrophysical Observatory
Victoria, B.C.

J. PATTERSON
Controller of the Meteorological Service of Canada, Toronto

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THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

VOL. XXXVII, NO. 6 JULY-AUGUST, 1943 WHOLE NO. 325

"ORDER IS HEAVEN'S FIRST LAW"

By A. E. JOHNS

> Order is Heaven's First Law; and this confest,
> Some are, and must be, greater than the rest,
> More rich, more wise; but who infers from hence
> That such are happier, shocks all common sense.
> POPE: Essay on Man—Epistle IV.

POPE in the above quotation gives us the topic for my address. By "order" he clearly meant rank, relative position, a condition where everything is so arranged as to play its proper part. And in Nature and Astronomy there is such ordering. We speak of the various cosmic units. In particular, below us in size there are three: the electron, the atom and the molecule. Above us, there are also three: the planets, of which our earth is a sample; the star, of which our sun is a sample; and the galaxy, of which our Milky Way is one. Certainly there is order in this sense, not only among men, as Pope suggested, but in the cosmic universe.

But the word "order" requires some page and a half in my Webster's dictionary for its definition. Like so many preachers, good and otherwise, I shall take my text as a point of departure and discuss "order" in the sense we usually mean when we speak of the Order of Nature, or of Nature as Governed by Law; and, in particular, I want to review some of the struggles man has made to understand this order and its laws. All science is based on the assumption and the belief that our universe is orderly. Otherwise if no order existed, it would be folly to look for it. We do believe that nature is orderly and man has been most persistent in his search for its laws. In fact we believe that orderliness is one of the most dominant features of creation. It extends from the least

to the greatest, from the electron to the galaxy. Up to the present we mortals have glimpsed some of the laws of nature, but by far the greater number of laws have not yet been found. It is a stimulating thought to conceive of the Creator as a great master builder, who is still creating our universe, and doing so in accordance with simple and yet profound laws; and to think of ourselves as having minds patterned after his, created in His image, and able to think his thoughts again after Him.

Rules for Reasoning. The great Newton has put down four simple Rules for Reasoning in Philosophy, and I paraphrase them here.

Rule I. We are to admit no more causes of natural things than such as are both true and sufficient to explain their appearances.

To this purpose the philosophers say that Nature does nothing in vain, and more is in vain when less will serve; for Nature is pleased with simplicity, and affects not the pomp or superfluous causes. "Why take two when one will do?"

Rule II. To the same natural effects, as far as possible, assign the same causes. As examples he cites, respiration in a man and in a beast, the fall of meteors in Europe and in America, the light of our kitchen fire and of the sun, the reflection of light on the earth and on the planets.

Rule III. The qualities of bodies . . . , which are found to belong to all bodies within the reach of our experiments, are to be esteemed the universal qualities of all bodies whatsoever. This rule is the basis of general induction and shows how clearly Newton was convinced of the universality of law. Gravity was a fact on the earth. He deduced that it held between the earth and the moon, and confirmed it by calculation. He then inferred it was universal.

Rule IV. In experimental philosophy we are to look upon propositions collected by general induction from phenomena as accurately or very nearly true—till such time as other phenomena occur, by which they may either be made more accurate or liable to exceptions.

In other words, stick to your law as found by experiment as long as, and only as long as it will fit the facts. One failure to obey the law invalidates the law. What a supreme test to put to any law of Nature!

We may abbreviate the four Rules thus:

1. Seek simple laws. Simplify.
2. Make each go as far as possible. Exploit.
3. Generalize.
4. Revise.

In one lecture it is impossible to trace in detail the history of man's search for law and order in our Universe. So I select a few examples.

The Saros was known to the Chaldeans so early that no date can be assigned to its discovery. The sun and moon were the dominant celestial bodies to the early observer and so it was natural to inquire first into their movements. Also an eclipse of either is such a striking event that records of eclipses began to be made. And so it was learned that every 6585 1/3 days, i.e., 18 years 11 1/3 days (or 18 years 10 1/3 days if the period had 5 leap years) the eclipses repeated. Why they repeated, the Chaldeans did not know, but continued observation showed that they did so. To the above period they gave the name *Saros*—a word meaning 60×60 or 3600 in their sexagesimal system, or simply *Repetition*.

Much later observations have shown us that this law is very nearly fulfilled only because of a number of very fortunate coincidences, the failure of any one of which would have invalidated the law. The figures below seem to me to be very striking.

223 lunations	$=$ 223 $\times$	29.5306	$=$ 6585.32 days
19 eclipse years	$=$ 19 $\times$	346.6201	$=$ 6585.78 days
239 anomalistic months	$=$ 239 $\times$	27.5546	$=$ 6585.55 days
242 nodical months	$=$ 242 $\times$	27.2122	$=$ 6585.36 days

or thus:

Sun, Moon, Earth line up 223 times in 6585.32 days
Sun, Node, Earth line up 19 times in 6585.78 days
Moon, Perigee, Earth line up 239 times in 6585.55 days
Moon, Node, Earth line up 242 times in 6585.36 days.

That the whole number of days is the same in all four cases is certainly remarkable. Since the first one is the actual period before an eclipse is said to repeat, it is the Saros, i.e., 18 years 11 1/3 days. The .32 means that the eclipse will happen on the earth almost 8 hours westward at each repetition so that after 3 such periods, the eclipse will occur practically at the same place on the earth. The

difference between the first two periods is almost exactly 11 hours, in which time the sun or earth travels 28′ of its orbit. So if at the beginning of a saros the earth, moon and sun are in line, at the beginning of the next saros the earth, moon and sun will be in line 28′ west of the former position. Hence each repetition of an eclipse after a saros will not be exactly like its predecessor, and very gradually the form will change. The first of a series will just graze the north (or south) pole of the earth, and each successive one will be about 180 miles south (or north) on the average of its previous latitude.

In the case of lunar eclipses there are first about 14 partial eclipses, which at first are very small and grow larger. Then about 22 total eclipses follow, after which there are about 14 partials. In all there are 48 to 50 eclipses in the series. Then the series terminates and the shadows pass above or below the earth for some 6000 years when another series begins. For the sun each eclipse repeats about 70 times, of which about 24 are partial, 18 total and 27 annular, and so lasts about 1260 years.

As I have already said, the Chaldeans had no idea why the eclipses repeated. It was only after Newton's discovery of the law of gravitation that an explanation was found for the regression of the nodes, the advancement of the line of apsides, the changing of the shape of the moon's path about the earth and the variation in the length of the month. It is said that consideration of the moon's motions was so difficult that it made even Newton's head ache.[1] There are still irregularities in its motion that have not yet been 'ironed out,' and a hundred terms or so have to be employed to secure the moon's position at any explicit moment—all coming from the one law of gravitation.

The Greek Astronomers. Astronomy may be said to have sprung from Babylon, but cosmology, distinct from mythological cosmology, dates only from Greece. "No sooner did an Ionian philosopher learn half a dozen geometrical propositions and hear that the phenomena of the heavens recur in cycles that he set to work to look for law

[1]Berry, "Short History of Astronomy," p. 240. "Newton once told Halley in despair that the lunar theory 'made his head ache and kept him awake so often that he would think of it no more'."

everywhere in nature and with an audacity amounting to insolence to construct a system of the Universe" (Heath, "Greek Astronomy," xii.) We can mention only a few important names. *Thales* was one of the Seven Wise men. One of his wise sayings is, "Of all things that are, the most ancient is God, for he is uncreated; the most beautiful is the universe, for it is God's workmanship; the greatest is Space, for it contains everything; the swiftest is Mind, for it speeds everywhere; the strongest is Necessity, for it masters all; the wisest is Time for it brings everything to light."

He had a great piece of good luck, for he predicted an eclipse of the sun which took place during a battle between the Lydians and the Medes—probably that of May 28, 585 B.C. No doubt he used the saros, but it often fails to locate exactly the path of totality, so I say he was very fortunate.

Pythagoras and his school, whose dates are about 580-500 B.C., had the idea that number is everything—not only does number represent the relations of the phenomena to each other, but is the substance of things, the cause of every phenomenon in nature. The celestial motions were performed with regularity, and the harmony of musical sounds depends on regular intervals. All the world was ruled by harmony, all the different heavenly revolutions produced different tones, so that each planet and the sphere of stars emitted its own particular musical sound, which our ears were unable to hear because we have heard them from our birth, though it was afterwards asserted that Pythagoras alone of all mortals could hear them.[2] Pythagoras believed the earth was a sphere and the circle came to be used more and more in astronomical theories. This belief of the earth's being a sphere is 2000 years older than the theory of the earth's rotation. The "seven" planets (Moon, Sun, Mercury, Venus, Mars, Jupiter, Saturn) are our spheres. The Pythagorean Philolaus (5th century, B.C.) had the idea that the earth and all the planets moved around some central fire—a first step in removing the earth from the centre of the universe according to man's conception.

[2]Kepler more than 2000 years later became enthusiastic about this idea of the music of the spheres, and actually wrote the tune each one played. See Berry, "Short History of Astronomy." The earth sang the notes, according to Kepler, Me, Fa, Me, "so that you may guess from them that in this abode of ours Misery and Famine prevail."

As time went on more and more spheres were invented to describe the various motions of the sun, moon and planets. *Eudoxus*, 409-356 B.C., stepped the number up to 27, there being 3 each for the sun and moon and 4 each for the planets and one for the stars. Each of the 4 would have its centre on the surface of the previous one—so things were getting rather complicated. Newton's Rule I was being badly violated (his plea for simplicity). Next I would mention *Apollonius* (latter half of 3rd century B.C.), for he showed that circles would do instead of spheres and suggested the epicycle. He was called *The Great Geometer* because of his work on the Conic Sections. I pause to recall their names to your mind—the ellipse, parabola, hyperbola. I fancy I can hear the utilitarians of his time saying, What's the use of all this theoretical stuff? as they say to-day of all the mathematical literature that is pouring from graduate universities, and which only a limited few can read. Who could foresee Kepler's and Newton's use of them, or their use in parabolic mirrors, search lights, telescopes? Who could have guessed that they were the paths of the heavenly bodies under the inverse square law of gravitation?

Hipparchus (2nd century B.C.)—The Father of Astronomy—deserves much credit, but I mention only his use of the eccentric and the epicycle. Since nature was perfect and the circle was the only perfect curve the heavenly bodies must move in circles—so they reasoned. But the planets moved backwards some times, and so the epicycle was invented.

The non-uniform motion of the sun in its orbit was quite well arranged for by the eccentric, in which the centre of the earth was not at the centre of the sun's orbit. By a proper location of the earth with respect to the centre, the error was less than 1′ everywhere.

For the moon he was less successful, and two arrangements of the crank-arm were necessary for Mercury and Venus as against the other planets.

Ptolemy (middle of 2nd century A.D.), preserved the works of Hipparchus, improved his lunar theory of epicycles but still got inadequate results. He also got better theories for the planets' motion.

Aristarchus (1st half of 3rd century B.C.) had put the sun at the centre of the universe and made the earth rotate and revolve. But

his views got little acceptance, and we get a break of 14 centuries from Ptolemy to Copernicus.

I close this brief review of Greek astronomy with Ptolemy's epigram, "I know that I am mortal and the creature of a day; but when I search out the massed wheeling circles of the stars my feet no longer touch the earth, but, side by side with Zeus himself I take my fill of ambrosia, the food of the gods."

Copernicus (1473-1543) the 400th anniversary of whose death we are commemorating this year, heads up the "Revolt from Authority." He dethroned the earth from its position as centre of the universe and put the sun in its place. To him the earth both rotated on its axis once a day and revolved about the sun once a year. Ptolemy had argued against rotation lest the earth fly to pieces. Copernicus remarked that there was much more danger to the celestial sphere, since its motion had to be so much more rapid. He reduced the earth to a tiny planet. However his revolt from authority was not complete. The circle still held sway and Copernicus still argued for it. "Nevertheless, it must be admitted that the motions are circular or are built up of many circles; . . . For the circle alone can bring back to us, through its motion made up of circles, the irregularities of the days and nights and the four seasons" ("Source Book of Astronomy," p. 3). So all the complicated system of epicycles remained.

This displacement of the earth from the centre of the universe caused a tremendous upheaval in the intellectual and religious world. Copernicus died before the storm broke.

Galileo (1564-1642) felt its full fury when he championed the views of Copernicus. The telescope which he had constructed opened out new aspects of astronomy to Galileo. With it he saw the four moons of Jupiter revolving about the planet, the phases of Venus, the rotation of the sun as indicated by the motion of the sun-spots, and the mountains on the moon. One cannot but be impressed with his brilliance as a controversial writer. To his enemies he could be very aggravating. When arguing for the rotation of the earth, he remarks that on the old hypothesis, the stars must have gone at different rates, those near the pole on little circles, those on the equator at tremendous speeds. But owing to precession which was known by Hipparchus, the position of the pole was continually

changing. Therefore the stars' rates were all changing. Some which were fixed at the former pole now have circular motions. How simple in comparison is the hypothesis that it is the earth and not the sky which revolves! (Berry, p. 164). Galileo begins to doubt the sanctity of the circle as the only possible curve of nature. He saw that the moon's surface was rough, not a perfect sphere, and he measured the mountains on the moon. "One of his scientific opponents, Ludovico delle Colombe, attempted to explain away the apparent contradictions between the old theory and the new observations by the ingenious suggestion that the apparent valleys in the moon were in reality filled with some invisible crystalline material, so that the moon was in fact perfectly spherical. To this Galileo replied that the idea was so excellent that he wished to extend its application, and accordingly maintained that the moon had on it mountains of this same invisible substance, at least ten times as high as any which he had observed" (Berry, p. 151).

Galileo had clearer conceptions of the true nature of motions and forces and knew Newton's first law of motion. He discovered the law of the pendulum and so made accurate clocks and accurate astronomy possible.

Kepler (1571-1630) was a contemporary of Galileo. His outstanding achievement was the final discarding of the circle as the orbit of a planet and its replacement by an ellipse. Even he tried for years to make the circle do. Fortunately he had available for testing his theories the unsurpassed observations of his immediate predecessor, Tycho Brahe (1546-1610). At one stage of his laborious calculations, Kepler secured almost perfect agreement between his theories and the observations of his master, Tycho Brahe. In fact, the greatest discrepancy amounted to only half the angular distance between Mizar and Alcor (11.5 minutes of arc) a quantity near the limit of Tycho Brahe's observations which were without optical aid. A man with less persistence and intellectual integrity, or with less confidence in the accuracy of the observations of another, would have been satisfied with his results. But the circle would not fit, and next he tried the ellipse whose properties Apollonius had invented so long before and lo they worked. So after twenty years of arduous work Kepler was able to condense the essential properties of the motions of the planets, as established by observations extending over 2000 years into the following three simple Laws:

I. The orbit of each of the planets is an ellipse with the sun at a focus.

II. Every planet moves in its orbit in such a way that the line joining it to the centre of the sun sweeps out equal areas in equal periods of time, whatever their length.

III. The squares of the periods of revolution of any two planets are in the same ratio as the cubes of their mean distances from the sun.

For 2200 years from Thales to Kepler men had speculated and searched for the true planetary system. Kepler had completed the search. Newton was to show that no other system would do.

Newton (1642-1727). The stage was now ready for Newton. Galileo had made a start in the knowledge of dynamics, and Kepler had found the true planetary laws.

First Newton laid down his three famous Laws of Motion:

I. Every body continues in a state of rest, or of uniform motion in a straight line, except in so far as it is compelled to change that state by force acting upon it. (Rest or uniform motion is the natural condition.)

II. Rate of change of momentum is proportional to the impressed force and takes place in the direction of the straight line in which the force acts. (The effect is proportional to the cause.)

III. Action and Reaction are equal and opposite.

Newton invented the calculus—a tool so powerful that now second year university students can use it to solve problems far beyond the ability of any but the ablest mathematicians of Newton's time. From Kepler's Laws and the Laws of Motion he deduced the Law of Universal Gravitation. In particular from Law II he showed that the force acting on the planet must be directed towards the sun. From Law I, the law must be the inverse square law and from Law III, coupled with his own laws of motion, he deduced the Law of Gravitation for the planets and showed that it depended in amount only on the mass of the planets. Then he turned the problem around and showed that if the law of gravitation held, the path must be not necessarily an ellipse but a conic section. If the law were one of repulsion as the inverse-square distance, the path would be the far arm of the hyperbola. The initial conditions settled the kind of path. The old idea had been that something was driving the planet

along. Now Newton's First Law stated that uniform motion was a natural thing. Also, any central force would cause equal areas to be described in equal times. Newton made a slight correction to Kepler's Third Law and produced two powerful formulas—one for weighing double stars, and one for determining the velocity in an orbit.

The law of gravitation is certainly a wonderful law. It fulfilled the first three of Newton's own Rules for Philosophers. It was simple. Newton certainly exploited it and carried its use to the bounds of the solar system. It was as general as it could be. *Every* particle in the *Universe* attracts *every other* particle with a force which varies as the product of their masses and inversely as the square of the distance between them. Expressed mathematically $F = Km_1m_2/d^2$. Rule IV Newton never had to use. It explained all the facts as he saw them, and all that were discovered until this century when Einstein found it necessary to make a slight correction. What a wonderful law it is! *Every particle*—regardless of the kind of material of which it is made, no matter whether liquid, solid or gas, no matter whether hot or cold, whether electrified, magnetized or hammered about shamefully—every particle attracts every other particle. Gravity cannot be screened off as can electrical forces or light or heat. The presence of other bodies cannot interfere with gravity. It goes blithely on its way—drawing every two particles together. It is a tiny force, but it works everywhere. The poet's remark "When I wave my arm I shake the stars in Ursa Major" is true. We cannot pluck a flower "without troubling a star." If two masses of a pound each were placed a foot apart, the force of gravity between them would amount to 3.32×10^{-11} pounds-weight—an imperceptible force. But this tiny force between large masses like the earth and the sun becomes tremendous. It must bend the earth out of its path 1/9 of an inch while it travels nearly 19 miles, and to do that it would be necessary to cover the whole surface of the earth with wires as large as telegraph wires, four coming out from each square inch, to get a combined cable strong enough to stand the strain: 36×10^{17} tons force. Similar stresses act through apparently empty space in all directions between all the different pairs of bodies in the universe.

Time will not suffice to catalogue Newton's accomplishments. His discovery of the composite nature of light, the binomial theorem,

and the method of fluxions were not essentially astronomical, but they were put to use in astronomy. And he did exploit his law of gravitation. The moon and the planets and the comets which had been lawless up to then were now amenable to law. So were the tides and the figure of the earth. The precession of the equinoxes was due, said Newton, to the gravitational pull of the moon and sun on the equatorial bulge of the earth. Gravity required the nodes of the moon's orbit to regress and the line of apsides of the moon to move forward.

Those most competent to judge showed immense respect for Newton's work. His rival Leibnitz said, "taking mathematics from the beginning of the world to the time when Newton lived, what he had done was much the better half." Lagrange, a great successor, said, "Newton was the greatest genius that ever existed and the most fortunate, for we cannot find more than once a system of the world to establish." But we all know Newton's modest estimate of his performances—"I do not know what I may appear to the world; but to myself I seem to have been only like a boy playing on the sea shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me."

It required the whole of the 18th century to exploit the law of gravitation in its applications to the motions of the solar system. In England (somewhere between 1727-1747) Bradley discovered "nutation" or nodding of the earth in its precessional motion. The pole of the earth sweeps out a large circle on the sky every 25,800 years and every 18.6 years there is a slight wave or nod in its motion. D'Alembert in 1748 explained that this motion was the result of the law of gravitation, being due to the uneven periodic pull of the moon on the earth's bulge. Euler, Clairaut, D'Alembert, Lagrange, Laplace were giants who continued to explore the consequences of the law of gravitation. Newton had completely solved the "two body" problem. For three or more bodies it was a different story. At the beginning of the 18th century the solar system had 18 recognized bodies—counting the sun, moon, the planets and their satellites. The problem was this. Given these 18 bodies and their positions and motions at any time, to deduce from their mutual gravitations by a process of mathematical calculation their positions

and motions at any other time; and to show that these agree with those actually observed. Since six elements were required to fix the orbit of any body at one time this was a tall order, and it has never been completely solved. Indeed it has been done only partially and under certain assumptions that may or may not be strictly true for the solar system. Another problem was to investigate the stability of the solar system. Could it last forever or would these mutual attractions ultimately destroy it? Laplace in his "Mécanique céleste" deduced some remarkable relations to prove that the system is stable.

However, our solar system has been found to be much more complicated, including, as it does, the sun, nine planets, 28 satellites, upwards of 2000 'vermin' of the skies, or planetoids, besides comets and meteors. However the masses are so small that their presence will not soon seriously affect the results. The mathematical discovery of Neptune was one of the great triumphs of the law of gravitation.

Modern astronomy has now extended the law of gravitation to the stars and to the galaxies. Double stars dance round each other just as the earth and the moon do. The same law holds and the same formula for weighing stars will succeed. My deceased friend W. E. Harper spent much of his life doing that very thing and has, I suppose, 'weighed' as many stars as any man up to the present. I had the interesting experience one autumn at Victoria of weighing one double star.

Newton's *space* was absolute, so was his *time*—a uniformly flowing stream moving on forever. Now we regard everything as relative and Einstein makes slight corrections to Newton's Law. This involves a change in the point of view. The centre has shifted from the man, to the earth, to the sun, to the centre of our galaxy, to the centre of all galaxies and all in motion. A paraphrase of Lambert's words (1800) will close the lecture. As we sit quietly here we are being whisked eastward at the rate of some 700 miles an hour due to the earth's motion on its axis. At six o'clock to-night we were driving downward 19 miles a second due to earth revolution. At the same time the sun's way carries us 12 miles each second in the direction of the star Vega, and the rotation of our galaxy carries us 175 miles a second towards the constellation Cepheus. The motion of our galaxy may be taking us at some tremendous speed, but all according to order. "Order is Heaven's First Law."

EXAMEN D'UN MIROIR PARABOLIQUE DE 40 CM. D'OUVERTURE

Par Paul H. Nadeau

Au cours de l'été de 1941, un groupe de membres de la Société astronomique de Québec, maintenant le Centre de Québec de la R.A.S.C., se faisaient autoriser à construire une coupole astronomique de seize pieds de diamètre. Cette dimension particulière avait été choisie en prévision du transport à l'observatoire de la Société, si jamais le projet devenait réalisable, d'un grand télescope Foucault dont l'Université Laval était propriétaire depuis de nombreuses années. La coupole ayant été achevée dans le temps prévu, il nous a été possible de la soumettre à toutes les épreuves requises avant la fin de l'été dernier. L'Université a alors consenti au prêt de l'instrument et a fait le nécessaire pour nous permettre de l'utiliser dès l'éclipse de Lune du 25 août.

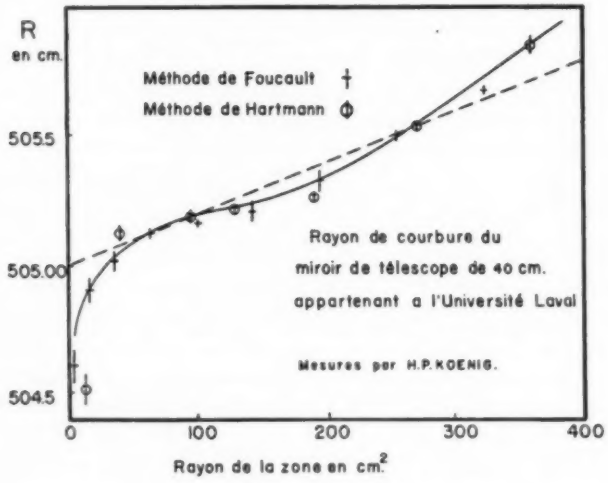
Ce télescope de 40 cm. d'ouverture porte l'inscription suivante: "Secrétan, à Paris, 1867". La commande en avait été placée l'année [1] précédente et le prix de revient estimé à 1.400 dollars. Le propriétaire, le Rév. J. B. L. Bolduc, devait s'en servir pour ses travaux personnels et le mettre en même temps à la disposition du Séminaire pendant les cours d'astronomie. En 1885, l'Université en devenait définitivement propriétaire.

Construit d'après les plans de Foucault, ce télescope est du type de certains instruments encore employés de nos jours en Europe, en particulier du célèbre télescope de 80 cm. de l'Observatoire de Marseille. Le tube et la monture équatoriale à fourche sont en bois, sauf les cercles gradués et les mouvements lents. L'oculaire étant formé d'un véritable microscope composé, le foyer principal se trouve situé à l'intérieur du tube. Le miroir, très homogène dans sa masse et d'une teinte vert-pâle, possède un poli parfait, ce qui expliquerait pour une bonne part la facilité avec laquelle nous avons pu l'argenter. Particularités assez bizarres, la surface de dos est courbe et le disque fixé dans le barillet un peu à la façon d'un objectif de lunette.

L'un des deux oculaires, à fort grossissement, est muni d'un micromètre, ce qui laisserait supposer que l'instrument servait surtout aux mesures d'étoiles doubles. Malheureusement, nous n'avons rien trouvé encore dans les archives de l'Université, qui pourrait nous renseigner sur les observations astronomiques effectuées avec ce télescope. Il est certain toutefois que, placé comme il l'a toujours été, semble-t-il, sur le toit de l'Université, dans une atmosphère chargée des fumées de la basse-ville et du port, l'instrument n'a jamais pu donner tout le rendement possible. Aussi, les autorités de l'Université ont-elles accueilli avec empressement le projet de transporter le télescope à l'observatoire du Centre de Québec, installé provisoirement à la Tour Martello, sur les Plaines d'Abraham. C'est l'endroit idéal en dedans des limites de la ville.

[1] Peu de temps auparavant, en 1864, le lieutenant E. D. Ashe, premier directeur de l'Observatoire de Québec, avait acheté de la Maison Alvin Clark une lunette équatoriale de huit pouces, au prix de 2.500 dollars.

Pendant que les préparatifs se poursuivaient à l'observatoire, le miroir du télescope était transporté à la Faculté des Sciences de l'Université Laval, en vue de soumettre sa surface à un examen détaillé. Grâce à l'amabilité du Dr Franco Rasetti, directeur du Département de Physique, MM. Koenig et Boivin, chargés de cette étude par la Société, ont pu obtenir l'usage d'un laboratoire et de différents instruments de précision. Leurs rapports respectifs ont été remis dernièrement à la Société, et, malgré quelques discordances dans les détails, il a été décidé de les accepter, l'étude proposée visant surtout à déterminer l'allure du paraboloïde. A ce point de vue, les renseignements fournis sont satisfaisants. . Mes



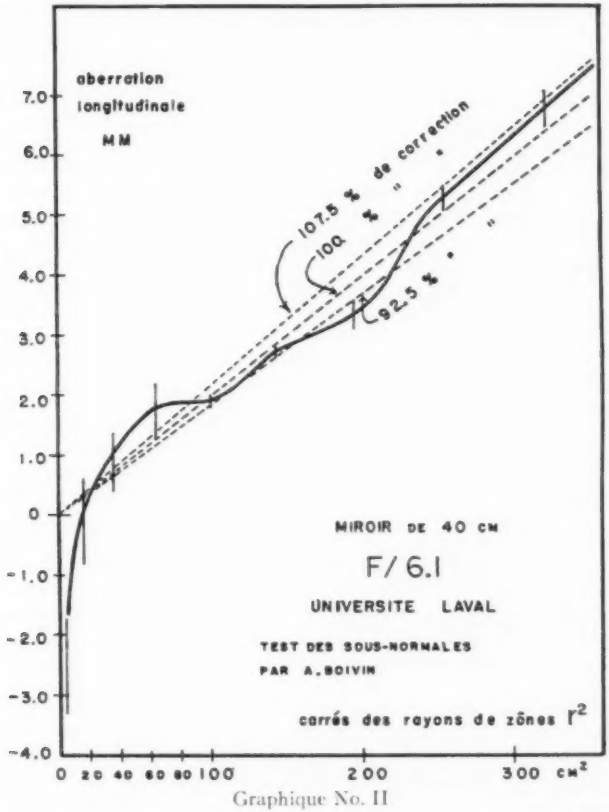
Graphique No. I

deux confrères du Centre de Québec ont bien voulu m'autoriser à puiser à volonté dans leurs résultats et je leur suis reconnaissant de me permettre ainsi de rédiger ce compte-rendu de leur étude.

M. Koenig a d'abord appliqué la méthode photographique de Hartmann[2], dont le principe consiste à déterminer l'aberration d'une zone par l'étude de pinceaux séparés. Dans la seconde partie de son travail, il a mesuré le déplacement du centre de courbure à mesure que la zone s'approche de la périphérie du miroir; c'est une application de la méthode de Foucault modifiée suivant G. W. Ritchey. Les huit paires de fenêtres de l'écran ont cependant été taillées d'égale

[2]Une description très détaillée en est donnée dans *Lunettes et Telescopes*, de Danjon et Couder, page 504. Voir aussi la revue *The Sky*, numéro de Janvier 1941.

largeur et disposées régulièrement de deux en deux centimètres. Tous ses résultats sont représentés sur le graphique I; la longueur des traits verticaux indique les limites d'erreur possible dans chacune de ces mesures.



Graphique No. II

Dans ses mesures des sous-normales, M. Boivin a employé le même écran que M. Koenig. Voici les moyennes finales qui ont servi à déterminer la courbe principale du graphique II:

Rayon de la zone	2 cm.	4 cm.	6 cm.	8 cm.	10 cm.	12 cm.	14 cm.	16 cm.	18 cm.
Aberrat. mm.	-2,7	0,0	1,0	1,7	2,0	2,6	3,3	5,4	6,8

À partir de ces points, M. Boivin a pu déterminer mathématiquement, en appliquant la méthode statistique des moments, la parabole qui s'adapte le mieux à la courbe représentée. Finalement, il a été conduit à admettre pour centre de courbure moyen, et par suite pour foyer principal, une valeur sensiblement plus faible que celle de M. Koenig, obtenue par mesure directe. Il a donné comme rapport d'ouverture 6,1 au lieu de 6,3, et évalué la tolérance à 7,5 pour cent au lieu de 8,2 pour cent.

Toutefois, les mesures de MM. Koenig et Boivin s'accordent lorsqu'il s'agit de nous renseigner sur les propriétés du solide différentiel. Le centre du miroir accuse une dépression très évidente, malgré l'imprécision des mesures dans cette région. A 75 mm., nous avons une zone saillante, et, aux alentours de 140 mm., une zone surbaissée qui couvre une surface beaucoup plus considérable du miroir. Le calcul, d'après le graphique de M. Boivin, montre que les quatre dixièmes de la surface sont en dehors des limites de tolérance et ont été insuffisamment corrigés.

Mais il est fort possible que l'on soit là en face d'un chiffre extrême. Les défauts du miroir seraient, paraît-il, compensés par l'oculaire spécial qui complète la combinaison de Foucault, ou, ce qui revient au même, seraient nécessaires à cause de l'oculaire, défectueux lui-même. Or, c'est précisément la remarque qui a été faite à propos du télescope de 80 cm. de l'Observatoire de Marseille, construit à la même époque (1862) que celui de l'Université Laval. Nous lisons dans le numéro d'Août-Septembre 1941 du *Journal des Observateurs*[3]: "Foucault a volontairement sacrifié la figure de son miroir en le retouchant pour corriger les défauts de son oculaire spécial". Cet oculaire a été trouvé "tout à fait défectueux", ajoute-t-on encore. Il est logique de croire qu'il en est de même pour notre télescope, puisqu'il est semblable en tous points à celui de Marseille. Il faudra cependant attendre la fin des hostilités avant d'aller aux renseignements et d'être définitivement fixé sur ce point. En attendant, l'usage régulier et intensif de notre télescope serait ce qui reste de mieux à faire pour connaître sa valeur optique.

L'étude de ce miroir n'est certes pas complète. Pressés par le temps, nous avons tenu tout de même à nous renseigner sur la valeur de notre télescope, avant de l'installer définitivement. Nous avons suivi ce conseil de l'éminent observateur et praticien qu'était le comte A. de la Baume-Pluvinel: "Un astronome doit "connaître son instrument à fond; il doit être capable de le démonter et de le "remonter, en s'assurant que les réglages les plus délicats ont été effectués. Ce "n'est pas trop demander non plus à un astronome de savoir "foucaulter" son "objectif et d'être en mesure de l'étudier par la méthode de Hartmann; l'astronome "d'aujourd'hui doit donc être doublé d'un physicien très averti."

Nous ne sommes pas devenus du coup des experts dans l'examen des miroirs de télescopes, mais lorsqu'il nous sera donné de passer à des études plus sérieuses, nous aurons déjà acquis une expérience très précieuse.

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[3]Avant-propos du mémoire de M. R. Jonckheere: *Étoiles doubles découvertes à l'Observatoire de Marseille.*

ON THE PHYSICAL ORIGIN OF P CYGNI-TYPE ABSORPTION LINES IN THE SPECTRUM OF M.W.C. 374

By C. S. Beals

THE peculiar emission line characteristics of M.W.C.[1] 374 (α, δ, 1900, $21^h32^m.2$, 47° 28′, Mag. 9.1 Beq) were discovered by Merrill[2] and his collaborators on objective prism plates at Mount Wilson. A description of the spectrum in the ordinary and ultra-violet regions has been given by Swings and Struve.[3] Observations at this observatory have revealed the principal characteristics of the spectrum in general agreement with Swings and Struve as follows: The most prominent features of the spectrum are the hydrogen lines which bear a general resemblance to those of the star H.D. 190073[4] and consist of P Cygni-type emission superimposed upon broad, winged absorption lines. Weak lines due to ionized metals have also been observed, while the presence of lines due to O II, N II and N III is suspected but blending effects combined with low contrast render such identifications uncertain. Calcium K appears as a double absorption line and at first a relationship with the complex K line of H.D. 190073 was suspected, but radial velocity measures have indicated that the red component of the double line is probably of interstellar origin. Such an identification of the line is strengthened by the simultaneous presence in the spectrum of the broad interstellar line at λ4430. The present paper is concerned with the forms and intensities of the hydrogen lines with special attention to their absorption components.

Observational Material

The observations on which the discussion is based consist of eight plates, five of which cover the region λ3900-4950, and three the region λ5800-6800. The plates in the ordinary region were secured with a single-prism arrangement of the spectrograph making use of two cameras with dispersions of 51 and 93 A per mm. at Hγ.

[1] Mount Wilson Catalogue: *Astroph. Journ.*, vol. 77, p. 88, 1933.
[2] *Astroph. Journ.*, vol. 76, p. 156, 1932.
[3] *Astroph. Journ.*, vol. 91, p. 577, 1940.
[4] *Astroph. Jour.*, vol. 77, p. 251, 1933. This Journal, vol. 35, p. 145, 1942.

In the visible region three prisms were used with a dispersion at Hα of 46 A per mm. Each plate carried a set of calibration steps put on with the aid of a rapidly rotating step sector. Microphotometer records were made of all spectra, using an instrument which permits the simultaneous recording of the star spectrum and the iron and neon comparison lines so that the tracings could be used for the measurement of both intensity and line displacement.

The Hydrogen Line Profiles

Profiles of all the Balmer series members down to Hζ were derived from the tracings, and typical examples are illustrated in Figs. 1 and 2. Figure 1 shows the profile of Hδ which consists of

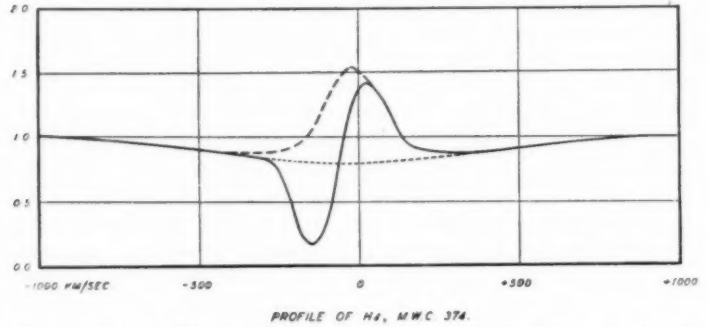

FIG. 1. Profile of Hδ. Dotted lines indicate reconstruction of emission line profile and underlying absorption line.

a typical P Cygni profile superimposed upon a fairly broad-winged symmetrical absorption line. The other hydrogen lines in the ordinary region are similar to Hδ, differing from it mainly in the relative intensities of their absorption and emission components. The profile Hα in Fig. 2 shows well marked differences from the later members of the series. It consists of a very strong emission line with wings apparently broad enough to fill in the underlying broad absorption. The emission line has a very intense maximum in a position corresponding to the peaks of the other emission lines. A second maximum appears considerably to the violet and the depression between the two has the appearance of absorption and

corresponds in velocity with the absorption components of the other P Cygni lines. It differs from them in that its minimum of intensity is still somewhat above the continuous spectrum of the star. If, as seems probable, this depression actually corresponds to an absorption line, then it appears to be absorption that acts to distort the emission component of the line and an estimate of the true absorption intensity is only possible if the unmodified form of the emission can be approximately re-created. On the assumption that the unmodified profile is symmetrical it is possible to do this, provided the centre of the line corresponding to the true radial velocity of the star can be found.

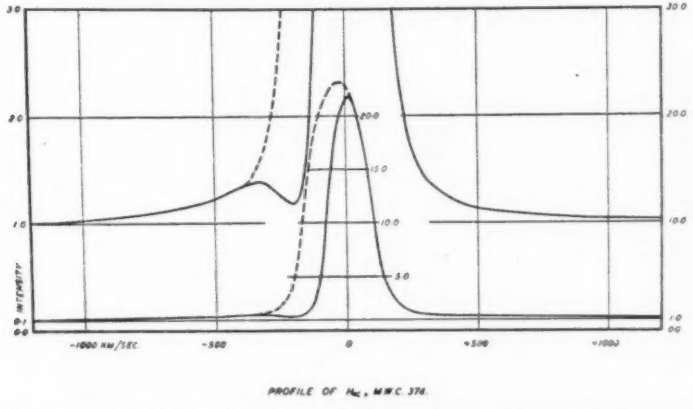

FIG. 2. Profile of Hα. Upper part of figure drawn to large scale shows only lower section of profile. Lower part shows same profile on a scale 1/10 as large. Dotted lines indicate reconstruction of emission line profile.

Radial Velocity of the Star

(a) *The Measured Line Displacements of P Cygni components:* The displacements of the components of the P Cygni lines from their normal positions expressed in terms of radial motion are given in Table I. The values of velocity have been derived from direct micrometer measurements of the plates and also from measurements of microphotometer tracings. Measures carried out by the two methods showed good agreement although in individual cases there

may be differences of interpretation of complex spectral features which will lead to divergent results. Values given in the table are weighted means depending upon dispersion and line quality. Only lines which showed sufficiently good agreement from plate to plate to make identification reasonably certain have been included in the table. The list of velocities includes two entries for Ca II, K, and it is believed that the strongly displaced component is a stellar line and that the less displaced line is due to absorption by interstellar matter.

TABLE I

MEASURED LINE DISPLACEMENTS OF P CYGNI COMPONENTS

Atom	λ	Absorption Velocity km./sec.	Emission Velocity km./sec.
Hα	6562.82	−198.7	+33.7
Hβ	4861.34	−186.2	+34.7
Hγ	4340.48	−148.3	+20.2
Hδ	4101.75	−146.5	+30.7
Hε	3970.08	−137.1	+22.8
Hζ	3889.05	−177.3	+ 8.0
He I	4921.93	− 90.1	.....
He I	4471.48	− 90.9	.....
He I	4143.77	− 40.7	.....
Mg II	4481.14	−113.9	.....
	4481.34		
Fe II	4351.77	−100.7	+19.2
Ca II	3933.68	−126.7	.....
Ca II	3933.68	− 10.6*	.....

*Believed to be interstellar.

In the past it has usually been assumed that the peaks of the emission lines of a P Cygni star gave the actual radial velocity, at least to a fair approximation, but a general consideration of the profile in Hα in Figure 1 suggests that the peak of the emission line line has been strongly displaced to the red by the effect of absorption. Further, the velocity derived from the emission lines has the large positive value of +25 km./sec., whereas practically all other early type stars in this region of the sky have negative velocities. It accordingly appears that less direct methods must be applied in

order to arrive at some estimate as to the actual radial velocity of the star relative to the observer.

(b) *The True Radial Velocity:* A rough estimate of the radial velocity of the star may be made from the approximately symmetrical wings of the Hα emission line. This method leads to a value of −39 km./sec., indicating that the peak of the line has been displaced approximately 63 km./sec. to the red by the effect of absorption.

A second estimate, which is also rather rough, may be made by a measurement of the wings of the broad hydrogen absorption lines which were evident in all the Balmer series later than Hα. The results of this method are given in Table II. Assuming that these

TABLE II

VELOCITY DISPLACEMENTS OF BROAD LINES

Line	Velocity km./sec.	Weight
Hβ	− 4	1
Hγ	−87	3
Hδ	−35	3
Hε	−52	1

Weighted mean velocity −52.8 km./sec.

broad lines are approximately undisplaced the radial velocity of the star comes out as −53 km./sec.

Still another means of estimating the radial velocity depends on the assumption that the radial velocity of the star is entirely determined by solar motion and galactic rotation. Such an estimate requires a knowledge of the star's distance. For the purpose of making estimates of distance there are available the intensity of the K line of calcium and the intensity of the broad interstellar line λ4430. These lines were measured on the two best plates in the ordinary region, giving values of equivalent width of 32 km./sec. for K and 92 km./sec. for λ4430. These values used in conjunction with the curves relating distance and interstellar line instensity[5] lead to a distance for the star of approximately 1000 parsecs.

Making use of this value of the distance we may derive the

[5] *Pub. Dom. Astroph. Obs.*, vol. 6, p. 333, 1937; *Mon. Not.* R.A.S., vol. 98, p. 398, 1938.

component of the velocity due to the radial component of galactic rotation from the equation used by Plaskett and Pearce[6]

$$\rho = rA \sin 2(l - l_0) \cos^2 b.$$

For $r = 1000$ parsecs, $l = 60°$, $b = 4°$, $l_0 = 324°.4$ and $A = 0.0155$ km./sec. per parsec, the value of the velocity ρ comes out

$$\rho = -2.99 \text{ km./sec.}$$

Adding to this the solar motion, -14 km./sec., the radial velocity of a star without peculiar motion in the vicinity of M.W.C. 374 is -17 km./sec. Some estimate of the probable error of a velocity computed in this way may be gained from the known peculiar motions of the early type stars which ordinarily have maximum values of the order of ± 20 km./sec.

From the above estimates it is clear that high precision cannot be expected in fixing the star's true velocity. However, within the range represented by the above values, the qualitative discussion of the nature of the P Cygni absorption lines later in the paper will not be affected. In order to make quantitative determinations of line-intensity it is necessary to fix on a definite velocity and the calculation can of course be carried out for a number of values of the velocity. For the purposes of this paper the calculations have been carried through for a velocity of -20 km./sec. This represents a conservative assumption as far as the line-intensities are concerned and the choice of a more negative velocity will result in higher values without otherwise altering the general character of the conclusions.

The Intensities of the P Cygni Absorption

Assuming the radial velocity of the star to be -20 km./sec.it is possible from considerations of symmetry to draw in the emission line profiles for all the Balmer lines and to derive the approximate shapes and intensities of the P Cygni absorption components. The dotted lines of Figs. 1 and 2 give an indication of the extent to which the emission lines have been modified by absorption. These illustrations make it clear that the absorption must act on the emission line as well as on the continuous spectrum of the star and that the absorbing layer must, in part at least, be located at a

[6] *Pub. Dom. Astroph. Obs.*, vol. 5, p. 292, 1931.

greater distance from the star than the layers producing the emission lines.

The absorption line profiles for the Balmer lines Hα and Hδ are shown in Fig. 3, while the equivalent widths of the absorption and both the observed and reconstructed emission lines are given in Table III. It is interesting to find that the intensity of the Hα absorption line, which on a casual inspection of the plates appears

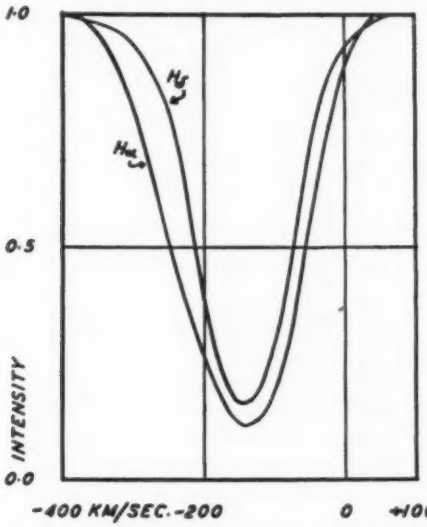

FIG. 3. Calculated Profiles of P Cygni absorption in Hα and Hδ. Note close correspondence in both intensity and velocity.

to have a small fraction of the intensity of the other lines, is actually the strongest of all. The other H lines, although definitely weaker, are still of comparable intensity and this suggests that the optical thickness is such as to approach saturation near the line centres.

The possible effect of occultation by the star's disc of part of the emitting shell has been disregarded in deriving these results. The general effect of occultation is to reduce the intensity of the red half

of the profile, causing an apparent shift of the emission line to the violet. The effect has been treated mathematically by Chandrasekhar[7] but it is difficult to make a quantitative application of the theory to a case where strong absorption is known to be present. Actually it appears that in any instance where the absorption has a strength comparable to that in M.W.C. 374, the influence of the

TABLE III

M.W.C. 374

ABSORPTION AND EMISSION INTENSITIES OF BALMER LINES

Equivalent Widths in km./sec.

Line	Absorption Intensity	Emission Intensity	Emission Intensity Uncorrected
Hα	182	6266	4256
Hβ	177	983	518
Hγ	167	369	193
Hδ	146	202	102
Hε	143	137	75
Hζ	119	112	53

absorption on the violet half of the profile is likely to be much more important than that of occultation on the red half. This follows from elementary geometrical considerations. Occultation can act only on a part of the envelope within a cylinder having the diameter of the central star while absorption can act on the entire shell which may be many times that diameter.

General Discussion

The most important conclusion to be drawn from the above analysis is that the emission components of the P Cygni lines of this star are subject to strong absorption by a layer of material farther from the stellar surface than that responsible for the emission lines. This conclusion, which was initially based on the peculiarities of the Hα profile, also follows from a study of the other Balmer lines once the approximate radial velocity of the star is known. The great strength of these absorption lines and the general similarity of the profiles appearing in the spectrum of M.W.C. 374 to

[7] *Monthly Not.* R.A.S., vol. 94, p. 522, 1934.

those of the other P Cygni stars, suggests that we are dealing with a general property of expanding envelopes rather than with a condition peculiar to one star. Such an inference receives support from the results of the study of another star, H.D. 190073,[8] where, by quite different methods, the conclusion was reached that the very intense P Cygni absorption components of the Ca II lines had their origin at a distance from the stellar surface almost twice that of the emission lines.[9]

On the basis of general theoretical considerations there appears to be no insuperable objection to the location of a strongly absorbing layer at a higher level than that responsible for emission in the envelopes of P Cygni stars or indeed of other emission line objects. The conditions necessary for the production of emission lines have been discussed by Zanstra[10] and may briefly be outlined as follows: In the region where emission takes place the atoms are subjected to the action of ionizing radiation of short wave-length and the main absorption of such radiation takes place in the region of the Lyman series limit. It is difficult to specify the effective width of the absorption region since the absorption coefficient falls off with distance from the series limit, but the observed intensities of lines in the spectra of various emission-line objects appear to require that a large part of the star's ultra-violet radiation be used up in the photo-electric ionization of the hydrogen atoms. The electrons ejected in this way eventually recombine with the atoms and a considerable proportion of the ultra violet energy absorbed reappears in the form of emission lines of the various hydrogen series. If the layer of hydrogen atoms is of sufficient optical thickness the effective extension of the emission shell will be limited by the complete absorption of the ionizing radiation.

Outside the emitting region, with the ionizing radiation at negligible intensity, the nature of the atomic transitions taking place will be governed by longer wave-length continuous stellar radiation and by the radiation of the various hydrogen emission lines. Of these by far the strongest will be Lyman α 2^2P°-1^2P since, as Zanstra

[8]This JOURNAL, vol. 36, p. 145, 1942.

[9]See comment on this result by Struve and Swings, *Astroph. Jour.*, vol. 96, p. 475, 1942.

[10]*Pub. Dom. Astroph. Obs.*, vol. 4, p. 209, 1930.

has shown, all transitions involving emission of the Balmer series and the Balmer continuous spectrum involve the emission of Lyman α as part of their cycle. In the process of absorbing the intense Lyman α radiation from the emitting region, atoms in the outer part of the shell will be excited to the 2^2P° state from which absorption of the Balmer series takes place. It accordingly appears reasonable to expect that a relatively large proportion of the atoms in this region would be in the 2^2P° state and that the strongest Balmer absorption would take place in this part of the shell.

The effect of such an outer absorbing layer in modifying the emission line profile may be expected to depend upon the velocity gradient of ejected atoms in a manner previously discussed in connection with the star H.D. 190073.[11] Atoms which suffer a retardation of their velocities in passing from the emitting to the absorbing level will give rise to absorption which will act strongly on the emission line itself and which will probably show itself mainly in a displacement of the peak of the emission line to the red. If, however, the atoms are accelerated in passing outward from the emission to the absorption regions then the absorption will affect mainly the continuous spectrum to the violet of the emission line and little displacement is to be expected.

The star M.W.C. 374 represents an example of the former case where the emission profiles are drastically modified by absorption and the peaks of the emission lines are shifted to the red. The star H.D. 51480, a P Cygni object with an Hα profile somewhat similar to that of M.W.C. 374, is also probably an example of this case. In addition to the peculiar shape of Hα its emission line velocity is +60 km./sec. while its velocity calculated as above from reasonable assumptions as to distance is of the order of +25 km./sec.

What is probably a similar case is cited by Struve and Sherman[12] in connection with the spectroscopic orbit of 29 Canis Majoris. They drew attention to a red shift of the emission lines of one component of the binary of approximately 75 km./sec. and they attribute this displacement to absorption effects within the shell. While the nature of such effects are not specified it seems reasonable to

[11] This JOURNAL, vol. 36, p. 145, 1942.
[12] *Astroph. Jour.*, vol. 93, p. 84, 1941.

suppose that they correspond to the physical processes outlined above.

Still another instance which may have a similar explanation is the red shift of the Wolf-Rayet bands of the binary star H.D. 193576 noted by O. C. Wilson.[13] In connection with this star, Wilson has discussed, but was inclined to reject, an explanation of the red shift based on absorption, partly because a similar shift was shown by both strong and weak lines. However, it may be noted that for the star M.W.C. 374 the emission velocity is approximately the same for lines of widely differing intensities so that an explanation of the red shift of the Wolf-Rayet bands as an effect of absorption may be entitled to more weight than Wilson was inclined to give it.

In contra-distinction to the above examples, all of which show marked red shifts which may reasonably be attributed to absorption, the well known emission line star P Cygni has an emission line velocity (-10.5 km./sec. for hydrogen) which is very close to the calculated value (-13 km./sec.) for a star of its spectral type and position in the sky. This lack of appreciable redward displacement would suggest that here the envelope is composed of atoms subject to outward acceleration in passing through the regions responsible for the observed emission and absorption lines. This conclusion is in satisfactory agreement with results derived from the spectrum of P Cygni by Struve[14] and by Beals[15] in 1935. They found from a study of the displaced absorption lines of the elements carbon, nitrogen and silicon, that increases of velocity of as much as 100 to 200 km./sec. occurred in passing from the inner to the outer levels of the envelope surrounding the star.

The differences in velocity gradient stated above, if they could be regarded as definitely established, might eventually lead to valuable information regarding relative values of surface gravity and other physical characteristics of the stellar surface. In this connection it may be of some significance to note that the star M.W.C. 374 with a negative velocity gradient is intrinsically nearly four magnitudes fainter than P Cygni which has a positive gradient. However, in any physically significant correlation it would be neces-

[13] *Astroph. Jour.*, vol. 91, p. 398, 1940; vol. 95, p. 402, 1942.

[14] *Astroph. Jour.*, vol. 81, p. 66, 1933.

[15] *Mon. Not.* R.A.S., vol. 95, p. 580, 1935.

sary to consider spectral type as well as absolute magnitude and the observational data are not at present sufficient to make this possible.

Summary

The profile of Hα in the spectrum of M.W.C. 374 consists of two emission maxima of greatly differing intensity, the stronger of the two being to the red. The remaining members of the Balmer series are normal P Cygni type lines but with the emission peaks (which coincide in velocity with the stronger emission maximum of Hα) shifted to 50 km./sec. or more to the red of the normal position as determined from other features of the spectrum. Evidence is presented which indicates that the unusual profile of Hα and the displacements to the red of other emission lines of the Balmer series are due to absorption by a layer of atoms located at a greater height above the stellar surface than the stratum responsible for emission.

The true intensities of the displaced absorption components of the Balmer lines of M.W.C. 374 are derived by a reconstruction of the unmodified emission line profiles and it is shown that the absorption is vey intense, approaching saturation in the line centres. It is suggested that the displaced absorption lines of all P Cygni stars normally have their origin in such an outer absorbing layer and theoretical reasons are cited in favour of this view.

It is pointed out that a displacement to the red of an emission line profile indicates that the absorbing atoms may be subject to a retardation of their velocities in passing outward from the region of emission to that of absorption while an undisplaced profile may be an indication of accelerated motion.

Dominion Astrophysical Observatory
Victoria, B.C.
October 16, 1942.

REVIEW OF PUBLICATION

Boundary-layer Problems in the Atmosphere and Ocean by C.-G. Rossby, B. Holzman, W. C. Jacobs, A. A. Kalinske, P. Light, B. Haurwitz, H. V. Sverdrup and R. B. Montgomery. Annals of the New York Academy of Sciences, vol. 44, art. 1, pp. 1-104, 1943. Price $1.25.

This pamphlet contains eight papers presented at a conference held March 6 and 7, 1943, on the important subject mentioned above. The titles of the separate papers as arranged in the order of their authors, are: (1) Introduction to the conference and some applications of boundary-layer theory to the physical geography of the middle west. 10 pp. (2) The influence of stability on evaporation. 6 pp. (3) Sources of atmospheric heat and moisture over the North Pacific and North Atlantic oceans. 22 pp. (4) Turbulence and the transport of sand and silt by wind. 14 pp. (5) Boundary-layer problems involved in snow melt. 14 pp. (6) The effect of a gradual wind change on the stability of waves. 12 pp. (7) On the ratio between heat conduction from the sea surface and heat used for evaporation. 8 pp. (8) Generalization for cylinders of Prandtl's linear assumption for mixing length. 15 pp.

At the end of each paper are comments by other workers in the same field, with replies by the author; and a list of references to literature.

Any student of these difficult subjects will surely find assistance in these solid scientific contributions.

C.A.C.

NOTES AND QUERIES

Communications are invited, especially from amateurs. The Editor will try to secure answers to queries.

"Swish" of the Aurora

Referring to the quotation from Humphreys' "Ways of the Weather" on page 168 of the April issue, Mr. David W. Rosebrugh, of Waterburg, Conn., writes:

After the astounding aurora of September 18, 1941, I learned that some good friends of mine had heard sounds which they associated with the aurora. I secured statements from them which I sent to Dr. C. W. Gartlein of Cornell who is heading up the Cornell-National Geographic Society study of aurorae which was started about the end of 1938. The following is a summary of my recollections of the remarks of Messrs. Edwin K. Ellis and Kenneth Pearce of Poughkeepsie, N. Y. These gentlemen established a camp for the night of September 18, 1941, somewhere north of Maniwaki, P.Q., at about latitude 46½°.

Before the normal hour of darkness they were walking over farm lands hunting for a spring of water, when Mr. Ellis remarked to Mr. Pearce, "Do you hear what I hear?" Both had heard an unusual noise and they then listened more carefully. They both agreed that they had never heard any noise quite like it before. They described it as being moderately loud and resembling the rustling of a silk dress or the continuous crushing of aluminum foil of the type once used around chocolate bars. They were not able to determine the source of the noise and could not account for it at the time in any other way than by associating it with the aurora which they then noticed for the first time as it had grown darker.

It is my recollection that Amundsen was the first and possibly the only one to suggest that the sounds associated with aurorae seen in the Antarctic were caused by the "freezing of breath." I remember reading this statement in one of his books many years ago, and I have seen the statement quoted many times since but without giving the source.

Obviously Amundsen's suggestion could not apply on September 18, 1941, as it was not freezing at the time.

The possibility that the noise of the aurora arises directly from the aurora itself would seem to be ruled out in the case of the aurora of September 18, 1941, by the fact that the aurora completely filled the sky over many thousands of observers, so that the noise, if caused directly by the aurora, should have been just as audible to thousands of observers as to two. Moreover the aurora floats high in the atmosphere and any noise from it coming down from these rarefied heights would probably be very faint and attenuated because the noise from one portion of the aurora, which is miles from another portion would not arrive until seconds or minutes later.

The aurora is apparently electrical in nature. The hissing of electric influence machines, transmission lines, and electrical apparatus on test are not unlike those noises described by Messrs. Ellis and Pearce. C. A. C.

Rainbows—Half a Dozen of Them

Speaking of my last-finished detective story, "The House without a Key," by Earl Derr Biggers, I got a little extra diversion out of his account of a drive to the Golf links taken by the hero John Quincy when on a visit to Hawaii:

> He drove up the Nuuanu Valley in Barbara's roadster . . . In that sheltered spot a brisk rain was falling, as is usually the case, though the sun was shining brightly. John Quincy had grown accustomed to this phenomenon; "liquid sunshine" the people of Hawaii call such rain, and pay no attention to it.

But there *was* a phenomenon to which he might well have paid attention, because the author of the book states that when they arrived—

> Half a dozen different rainbows added to the beauty of the Country Club Links.

This extraordinary sight is referred to quite casually; be it noted that he had not as yet been to the "locker room," since he saw the rainbows from his seat in the motor car. Later we are told that "they putted through a rainbow and returned to the locker room." The whole thing may of course have been the fault of the locker room (as many men "see double" after having been in a locker room), and the incident might have been passed by if on arriving they had seen only a double rainbow. The writer saw a double rainbow in the Adirondacks and took a motion picture in colour, which proved that a locker room had nothing to do with it.

The production of a rainbow, of course, depends on the relative positions of the eye of the observer, the sun and the falling rain-drops. Usually only one rainbow—the primary—is seen. A secondary—or "double"—rainbow can be produced by an expert with the garden hose, but in these days, as "quoth the raven," nevermore!

There was a Greek mythical character named Argus who had eyes all over his body, which were later transferred to the tail of the peacock. This gentleman could have seen many rainbows. Argus with his countless eyes originally denoted the starry heavens.

F.T.S.

MEETINGS OF THE SOCIETY

AT MONTREAL

February 11, 1943.—The third of the series of popular lectures was given by Mr. A. V. Madge, his subject being "Comets and Meteors."

In ancient times, Mr. Madge said, comets were looked upon as signs of the wrath of heaven. Edmund Halley's prediction that the great comet of 1682 would be visible again in 1758, in 1835 and 1910 had some effect upon the thought of the time, and when this comet was picked up on Christmas Eve, 1758, it was realized that Newton's Law of Universal Gravitation had been put to its first test and had won.

A comet when first viewed is just a hazy patch of light somewhat like a faint globular nebula. After a few hours we notice that it has moved in relation to the stars. Gradually it becomes brighter and finally we can see through the telescope the "nucleus", or bright centre, the "coma", or gaseous envelope surrounding the nucleus, and the "tail." The tail does not follow the comet but it is always directed away from the sun for it is composed of minute particles driven out from the nucleus by solar radiation pressure. The density of the tail is about a hundred-thousandth that of air at sea level. In 1910, when the head of Halley's comet passed between the earth and the sun, the solar light was not even dimmed. The head of a comet varies in size from time to time and the length of the tail is even more variable. If a tail is visible to the naked eye it is usually not less than five or ten million miles in length. Mr. Madge then spoke of the origin of comets. One theory is that comets have been accidentally swept up by the solar system during its flight through space. Another is that a gigantic eruption occurred on the planet Jupiter many ages past, comets being formed of the debris. It is also frequently said that a comet moving on a hyperbolic orbit must have come from outside our solar system.

Turning to meteors, Mr. Madge said that it has been estimated that over one hundred million meteors strike the earth's atmosphere every twenty-four hours, these ranging in size from a grain of sand to boulders weighing many tons. Entering the earth's atmosphere at a speed of from 20 to 50 miles a second, these particles of iron or stone ignite and are generally completely vaporized. Occasionally a meteor is so large that the vaporizing process is not completed before the meteor strikes the earth. It is then called a meteorite. Approximately 90 per cent. of the meteor is fused away and only 10 per cent. reaches the earth in compact form. Meteorites contain some thirty elements identical with those found on the earth and have been divided into three groups, (1) Siderites (metallic or iron), (2) Aerolites (stony) and (3) Siderolites (stony-iron). As great showers of meteors occur when the earth intersects the orbit of a comet it is commonly accepted that meteors result from the disintegration of comets.

In closing Mr. Madge expressed a hope that members of the Centre would take an active part in meteor observing, pointing out that amateur observers can make very valuable contributions.

ISABEL K. WILLIAMSON, *Recording Secretary.*

Observation Meetings held at Ville Marie Observatory.—Last fall it was decided to continue the weekly observation meetings during the winter months but to change the night of meeting from Thursday to Saturday. It was arranged to have two members of the Telescope Committee in attendance at the Observatory every Saturday evening from 7.30 p.m. to 9.30 p.m. Unfortunately, the Weather Man upset our plans. Saturday evenings were often cloudy, if not stormy, and on the few occasions when the sky was clear the thermometer registered below zero. However, we did hold eight observation meetings during the three winter months with a total attendance of fifty-three.

The rings of Saturn and the moons of Jupiter proved the main attractions at these meetings. Some of our newer members viewed these planets through a telescope for the first time. The nebula in Orion and the Pleiades were also popular. On November 28 the ten members present were fortunate in seeing the new comet Oterma. This comet was viewed again at the meeting on December 26. The early-comers on February 27 saw Whipple's Comet but that portion of the sky soon clouded over. Other observations included Beta Cygni, Beta Cephei, the double cluster in Perseus, M56, Polaris, Castor, M35, M37, M38, and the moon in its different phases. Five members recorded the partial eclipse of the moon on February 19-20 and are preparing a detailed report of this observation.

10th March 1943. ISABEL K. WILLIAMSON, *Recording Secretary.*

AT WINNIPEG

March 11, 1943.—The regular meeting of the Winnipeg Centre was held in theatre "F," University of Manitoba, with the president, Mr. V. C. Jones, in the chair.

Ft. Lieut. D. R. P. Coats introduced the speaker of the evening, Ft. Lieut. Stewart Mackie, who is signals officer at No. 3 Wireless School at Tuxedo.

The speaker said that radio is the modern magic that guides planes back to their bases.

In the last world war Zeppelin airships asked for directions from their bases. Direction-finding stations in England plotted their course and knew where to make preparations to meet them. On May 30, 1916, activity at Wilhemshaven was picked up by D. F. Stations. When the transmitters moved 2° or 3° clever operators guessed that the sources of messages were boats that must be moving out to sea. The British fleet was sent to meet the enemy. This it did at Jutland with well-known results.

There are four components of radio direction finders. These are: (1) A re-

ceiver that is capable of picking up radio telephony—either continuous or semi-continuous. (2) A non-directive aerial—a vertical wire is best. (3) A directive aerial, or loop, which causes different intensity of the signals as it is rotated through 360°—thus showing the line on which the transmitter is located. (4) A sense circuit to tell which direction on that line the transmitter is situated.

Other types of aerial that have their particular uses in some work are the right-angle and the parabolic reflector.

The loop aerial gives its maximum signal when edge-on and its minimum signal when at right-angles to the transmitter. The radio operator uses the minimum signal to find the line of the transmitter. (By means of a geometrical diagram the lecturer explained just how the transmitter is located.)

The sense circuit has two coils on two circuits close to each other. By rotating a loop on one circuit the maximum signal is heard, but when the loop is rotated to a position 180° away, one circuit is reversed and the signal is nullified. This shows the direction of the transmitter.

Many things cause irregularities in the receiving set. Some of these are:—rain or ice on the plane; the night effect (one half hour before sunset and a half hour after sunrise); boats being on the magnetic meridian; readings of 90° and 270° from the ship's head; coastal refractions due to depth of water, height of land, etc.

Radio waves were discussed in some detail; and the fan marker to assist pilots to land safely was explained. Also high-frequency locators and other "secret" possibilities were noted.

Discussion closed a most interesting lecture.

OLIVE A. ARMSTRONG, *Press Secretary.*

April 2, 1943.—The regular meeting of the Winnipeg Centre was held at 8.15 p.m. in theatre "F," University of Manitoba. The president, Mr. V. C. Jones, was in the chair.

Mr. R. D. Colquette gave a five-minute talk on "Astronomy in the News."

The lecture was given by Ft. Lieut. M. C. Minton of Rivers Navigation School. He commenced by saying that navigators of planes fly by contact navigation below the clouds, by radio direction in the clouds and by celestial navigation above the clouds. Over Europe to-day the ordinary celestial navigation is not used as the enemy defenders have means of finding the exact course and position of a plane that flies on an even keel. Every plane must continually weave from side to side, and in such a plane the old instruments cannot be used. Demonstrations with the astro-compass made it appear very simple to find the course on which the plane flies. The wind that causes a drift from this course can best be found by getting "pin points" from the ground. Then the true bearing can be calculated. Navigators, from their tables, can identify stars which they find to have a certain altitude and azimuth but they are supposed to know the navigation stars.

The bubble sextant was next demonstrated. The old model that was used averaged six different altitudes in one reading. Newer ones do much better than this. From the altitude of one star a "fix" can be plotted. This will be a circle whose radius is one nautical mile for each minute of angle from the sub-stellar point. A second reading from another star gives another "fix." Three "fixes" make the possibility of error less. By using Polaris as the observed star and correcting the reading the necessary fraction of a degree the latitude may be found directly. By using a star on the meridian when the time is known the longitude may be found directly.

Several interesting stories of student navigators' errors were told and hints of some of the forthcoming secret equipment were given.

This lecture was the final one of the winter series on navigation and was much appreciated for its masterly presentation.

OLIVE A. ARMSTRONG, *Press Secretary.*

AT TORONTO

March 2, 1943.—The Society met in the McLennan Laboratory, University of Toronto, at 8.00 p.m., Miss R. J. Northcott in the chair. The Chairman brought to attention of members recent newspaper reports indicating that Lieut. George H. Tidy, a member of the Society and formerly attached to the David Dunlap Observatory, who was believed to have been lost with H.M.S. Exeter, is a prisoner of war in Japan.

Dr. D. W. Best gave a brief outline of information concerning "The Galaxy," following which members and visitors were invited to submit written queries for answer. The outline covered characteristics of the sun and other stars, spectra, temperature sequence, period-luminosity relation, radial velocity, binary and multiple stars, variable stars, novae, clusters, nebulae and interstellar matter.

Of particular interest was the comparison of certain features of the nearest stars with those of the brightest stars. According to "The Milky Way" by Bok, there are 47 stars closer to us than sixteen light-years, though these comprise only 35 separate systems since a number are multiple systems. The nearest stars are dwarf stars and in general are of late spectral class. They are faint stars, for only ten are visible to the naked eye. The brightest stars, on the contrary, are all giants and supergiants of all spectral classes. They are very luminous objects, for the twenty stars that appear brightest in the sky are all more luminous than the sun. Dr. Best and others answered a large number of questions turned in on the blank slips which had been handed out before the meeting.

Dr. Helen S. Hogg, in the third paper on "Major Contributions of the Twentieth Century to Astronomy," spoke on "Giant Reflecting Telescopes." She traced the early development of the telescope from Galileo's 1¼-inch refractor, through the unwieldy tubes up to 300 feet long made in the late 17th and early

18th centuries in an attempt to overcome chromatic aberration, down to more modern types.

After Sir William Herschel's reflectors, bigger and better telescopes were designed. In 1848 one was built at Parsontown, Ireland, by William Parsons, Earl of Rosse, with a six-foot speculum (copper and tin) mirror. This was used until 1879, and was especially successful in showing the spiral character of extra-galactic nebulae. Its greatest disadvantage was the mounting which permitted observation in a limited space of only 7½° on either side of the meridian. At that time this was not a serious handicap, but with modern photographic technique requiring the telescope to follow the movements of stars during long exposures such an instrument would be of little use.

During the 19th century there was a swing back to refracting telescopes with optical systems which overcame chromatic aberration and other deficiencies found in the earlier refractors. The two largest—the 40-inch at Yerkes and 36-inch at Lick—are probably the biggest for many years to come. The 20th century brought larger and larger reflectors again, the largest of which now in use is the 100-inch at Mount Wilson.

By 1928 plans were already under way for the $6,000,000 instrument with a 200-inch mirror now being constructed at Pasadena in California. Under leadership of Dr. George Ellery Hale the work was started in 1930 with the construction of a machine shop at the California Institute of Technology. Work on the huge 200-inch disc of Pyrex glass began the next year after original plans to use fused quartz were abandoned. In 1933 an optical shop was set up in Pasadena in a specially insulated building in readiness for arrival of the huge mirror disc. After investigation of seeing qualities at many sites, Mount Palomar was chosen in 1934 and construction of the huge dome began next year. A million-gallon water reservoir was built and a paved highway constructed up the mountainside at cost of $1,500,000.

"Work on the 200-inch telescope and final polishing of the disc has been abandoned for the duration," Dr. Hogg said. "Our latest information is that a full year's work will be required to finish the job after the war." Two auxiliary telescopes to the 200-inch, "patrol cameras which browse the skies," are already at work on Mount Palomar. An 18-inch Schmidt camera (f:2) was put into operation in 1936. It covers an area of sky about 6,000 times that of the 200-inch and reaches stars of 18th magnitude in 40 minutes. An 8-inch Schmidt (f:1) has been in use since 1940 and can photograph the entire visible sky in three or four nights. Work on a 48-inch Schmidt (f:2.5) has been interrupted by the war.

The new 200-inch telescope when completed will, it is expected, be used mainly on distant nebulae, clusters, star fields and for study of planetary radiation. It is unlikely that any extensive use will be made of the huge telescope in studying planetary or lunar surfaces. "Probably its greatest use will be to take us 1,000,000,000 light-years out into space—or a billion years back into time if you prefer to express it that way," the speaker said.

FREDERIC L. TROYER, *Recorder.*

AT VANCOUVER

April 14, 1942.—The 83rd monthly meeting was held as usual in Science 200, University of British Columbia, the speaker being Dr. C. S. Beals of the Dominion Astrophysical Observatory, Victoria, B.C.

To introduce his topic, "The Bright Line Stars," the speaker discussed the various types of spectra, continuous, emission (bright) line, absorption line, and demonstrated them on the screen. In general, continuous spectra come from hot solids; liquids, or gases under pressure (e.g., in stars); emission line spectra from excited gases, and absorption line spectra from a source of a continuous spectrum seen through a relatively cool gas. The latter is most common in astrophysics. Dr. Beals showed that the latter type is due to the absorption of the stars' atmospheres, and also how the various lines are used to identify the elements in the stars and by their intensity indicate the stellar temperature.

However, the stars showing emission as well as absorption lines present a more difficult problem, especially if a solar model is used, since a thin atmosphere is quite unable to produce emission lines. A clue to the origin of emission lines is found in that they appear in the corona of the sun during an eclipse but are drowned out when the sun's disk reappears. Also emission lines occur in the spectra of planetary nebulae probably due to excitation by ultra-violet radiation. The stellar spectra containing emission lines include those of Novae, Wolf-Rayet, P Cygni and Be stars. The Novae have rapidly expanding atmospheres; and the Wolf-Rayet and P Cygni spectra exhibit a shift to the violet, indicating a similar process or at least a rapid stream of gases pouring out into space. The less intense and narrower lines of P Cygni indicate a slower action. Further, these types of stars are all at high temperatures, thus constituting a good source of ultra-violet radiation.

The emission line spectra may be explained, therefore, by the unusually large atmospheres and plentiful ultra-violet radiation of the stars emitting them, such conditions being necessary for their observation.

May 12, 1942.—The annual Dinner Meeting was held in the Brock Memorial Building, University of British Columbia. The speaker of the evening was Mr. R. K. Brown of the R.C.A.F. Radio Technicians, and his subject was "Radio."

The speaker began by explaining the difference between alternating current and direct current and the result of combining the two. Frequency of alternation was shown to be one of the important properties of alternating currents. They can be divided into two major groups, audio-frequency (16 to 16,000 cycles/second) and radio frequency (100 to 100,000 kilocycles/second). Various A.C. wave forms were shown on a cathode ray oscilloscope.

The speaker then proceeded to show coils and condensers and explain their function. He showed how they could be used to produce electromagnetic waves. These waves were described as an alternating magnetic field and an alternating electrostatic field at right angles to each other, moving away from the source with the speed of light.

A radio transmitter was described: (1) as a generator of radio-frequency alternating currents; (2) as a radiating system whereby these currents give rise to electro-magnetic radiation; (3) as means of impressing speech or music on the radio waves (modulation).

Modulation was demonstrated using two beat-frequency oscillators and an oscilloscope to show how a radio wave can be varied in amplitude.

The speaker used a standard broadcast receiver mounted vertically on a large board 30 by 48 inches to demonstrate the function of radio receivers. The progress of the incoming signal from aerial to loud speaker was explained. This included the tuned circuit as a signal selector, amplification, detection and sound production. The shapes of the various wave forms from point to point through the receiver were shown on a battery of four 'scopes connected to the appropriate points. The advantage of the superheterodyne circuit in giving high quality amplification and a high degree of selectivity was particularly stressed by the speaker.

He concluded with a very brief résumé of some of the recent developments in radio. These included automatic volume control, the cathode ray oscilloscope (described as a specially adapted electron gun), frequency modulation, television, and, last but not least, radio locators for locating enemy aeroplanes and submarines.

H. D. SMITH, *Secretary.*

À QUÉBEC

Le 5 février 1943.—La réunion de février a été tenue dans la salle des cours de physique et de chimie de l'École Technique, sur l'invitation du Président, M. Marie-Louis Carrier, professeur à cette institution. M. Henri Paul Koenig, M.Sc., conférencier à cette réunion, avait choisi pour sujet: Le test de Foucault et ses applications. M. Koenig a d'abord décrit le télescope de Newton, puis il a expliqué le rôle de son élément essentiel, le miroir parabolique, dont il a énuméré les différentes caractéristiques.

Le test de Foucault à la lame de couteau est un moyen facile d'étudier la surface d'un miroir. Au moyen de certains perfectionnements apportés à l'installation primitive de Foucault, le test peut fournir des renseignements quantitatifs. Il suffit de disposer d'un écran, qui laisse à découvert une seule zone du miroir à la fois, et d'une vis micrométrique permettant d'enregistrer des déplacements de l'ordre du dixième de millimètre. Dans le cas d'un miroir parabolique, le centre de courbure des zones augmente à mesure que l'on s'approche des bords du miroir, mais cette augmentation doit se faire suivant une loi bien précise. Si, sur un graphique, l'on met en abcisse les rayons moyens des zones et en ordonnée le déplacement du centre de courbure par rapport à un point quelconque, nous obtenons une courbe représentative de la surface étudiée, avec une précision d'un ordre supérieur à celui de la longueur d'onde lumineuse. En traçant de part et d'autre de cette courbe les courbes de tolérance maximum, telle que calculée pour le miroir en question, on peut déterminer les zones qui s'éloignent trop des limites théoriques et au besoin les corriger.

La causerie a été suivie avec beaucoup d'intérêt par un auditoire d'environ quatre-vingts personnes, parmi lesquelles on remarquait un grand nombre d'étudiants des cours supérieurs de l'École Technique.

Pour finir, M. Koenig a donné une démonstration sur un miroir de dix pouces, taillé par l'un des membres du Centre de Québec de la R.A.S.C.

PAUL H. NADEAU, *secrétaire.*

Le 19 mars 1943.—Cette réunion a été tenue à l'Université Laval, dans l'amphithéâtre du Laboratoire Lavoisier. Comme le conférencier désigné pour cette réunion, M. Lucien Pouliot, Trésorier, devait parler du télescope du Mont Palomar, un sujet éminemment populaire, il a été décidé d'inviter les membres de quelques groupements intellectuels de la ville. L'assistance a pu ainsi être portée à une soixantaine de personnes.

M. Pouliot s'est surtout appliqué à relater les difficultés rencontrées pendant la réalisation de cette merveille de technique et d'ingéniosité qu'est le télescope de 200 pouces, et il a mis en relief le parti que les ingénieurs ont su tirer de leurs propres idées et de celles qui leur étaient soumises de partout.

La silice pure ou quartz, à cause de son faible coefficient de dilatation thermique, était considérée comme la substance idéale pour le miroir de 200 pouces. Mais les premiers essais du Dr. Elihu Thompson ont conduit à un échec complet: plus de 600.000 dollars ont été engloutis dans ses recherches. Comme on était alors en pleine crise économique (1929), on a décidé d'abandonner cette matière. Le verre Pyrex a alors été choisi et l'entreprise confiée à Corning Glass Works, dont les ingénieurs, dirigés par Mr. George McCauley, avaient déjà réussi la coulée d'un disque de 82½ pouces, celui de l'Observatoire McDonald.

Mais le dos du disque de 200 pouces doit être à nervure radiale pour en diminuer le poids et faciliter son équilibre thermique. Toute une série de problèmes nouveaux se posent dès lors devant les ingénieurs: il va falloir développer une technique spéciale en essayant de couler des disques de 30, 60 et 120 pouces, avant de se risquer sur le disque final. La coulée du 30 pouces n'est pas un succès du premier coup. Le ciment, qui retient les blocs de brique réfractaire collés au fond du moule, ne résiste pas à la chaleur; il faut trouver autre chose. Le deuxième essai donne satisfaction. Le disque de 60 pouces est coulé avec un succès relatif, toujours à cause des fameux blocs qui remontent à la surface du verre fondu. Le 120 pouces, par contre, est une réussite complète dès le premier essai, et l'on entreprend la coulée du 200 pouces. Les boulons d'acier, qui retenaient les blocs au fond du moule, cèdent cette fois sous l'action de la chaleur, et il faudra organiser un système de refroidissement à l'air. Ce premier disque de 200 pouces est tout de même conservé: on s'en servira pour mettre au point une théorie du recuit. Le deuxième essai a réussi. On était alors à la fin de 1934, deux ans après l'octroi du contrat à Corning Glass.

Les ingénieurs d'en avaient pas fini cependant avec les difficultés. Pendant que le disque refroidit lentement, la rivière Chemung, qui passe à côté de l'établissement, se met subitement à monter, et l'on doit suspendre l'opération trois mois avant la date prévue. Mais heureusement, la recuite est suffisante et le

miroir reconnu bon. Le transport se fit sans accident, sinon sans difficulté, et enfin le disque arriva à Pasadena au mois d'avril 1936. La taille dura jusqu'en avril 1938 et le polissage juqu'en août 1941. L'entrée des États-Unis en guerre, au mois de décembre 1941, est venue suspendre les travaux à ce stage.

Quand des conditions meilleures permettront de compléter le miroir, il faudra transformer son sphéroïde en paraboloïde, c'est-à-dire enlever dans ses parties centrales cinq millièmes de pouces de verre au maximum. Ce seul travail prendra au moins un an, surtout à cause des examens fréquents qu'il nécessite. La coupole et la monture spéciale du télescope avec son axe polaire en forme de fer à cheval, sont complètement terminées à l'heure actuelle.

Pour conclure, M. Pouliot a donné quelques chiffres sur la puissance du télescope de 200 pouces. Quatre fois plus grand que celui du Mont Wilson, son objectif pourra capter la lumière des étoiles de 20e magnitude et demie et la concentrer assez pour la rendre visible à l'oeil humain. Le pouvoir séparateur sera de 3 centièmes de seconde d'arc, ce qui correspond sur la Lune à une distance de 28 pieds. Deux points ainsi séparés pourront être vus distincts sur notre satellite, ramené à 25 milles de nous par l'emploi d'un oculaire grossissant de 10,000 fois.

La causerie était illustrée de vingt-sept projections lumineuses extraites du livre de David O. Woodbury, *The Glass Giant of Palomar*, du JOURNAL de la R.A.S.C. et de différentes revues.

PAUL H. NADEAU, *secrétaire*.

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